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CONSTRUCTION WITH FIELD MOLDABLE POLYURETHANE FOAM BLOCKS. (U)

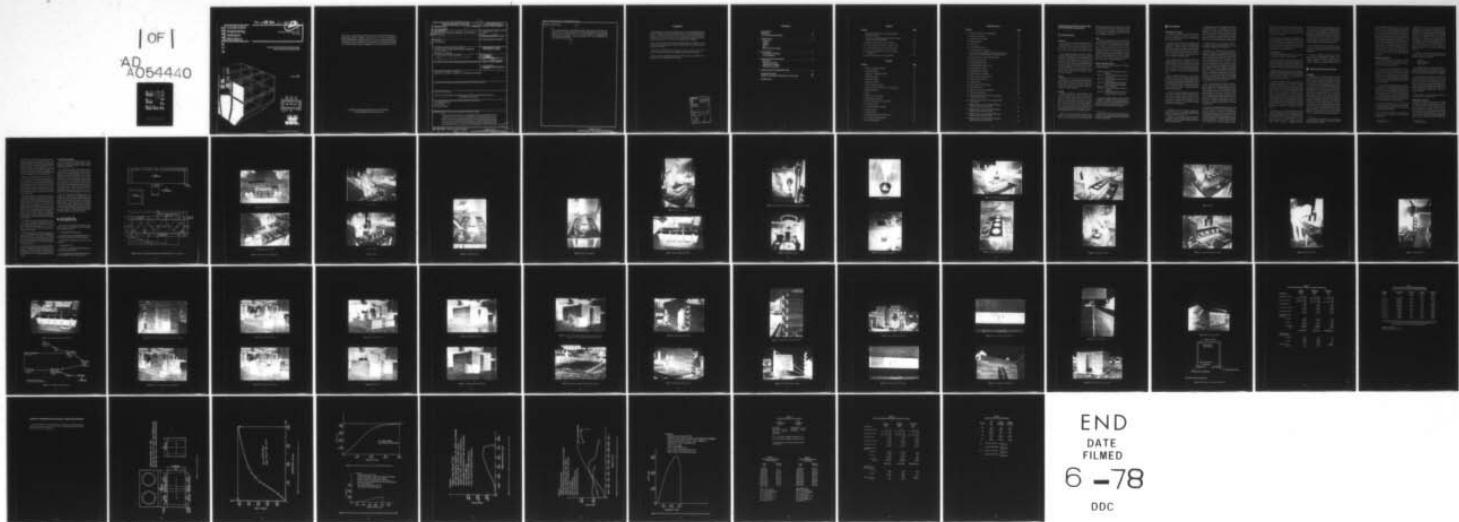
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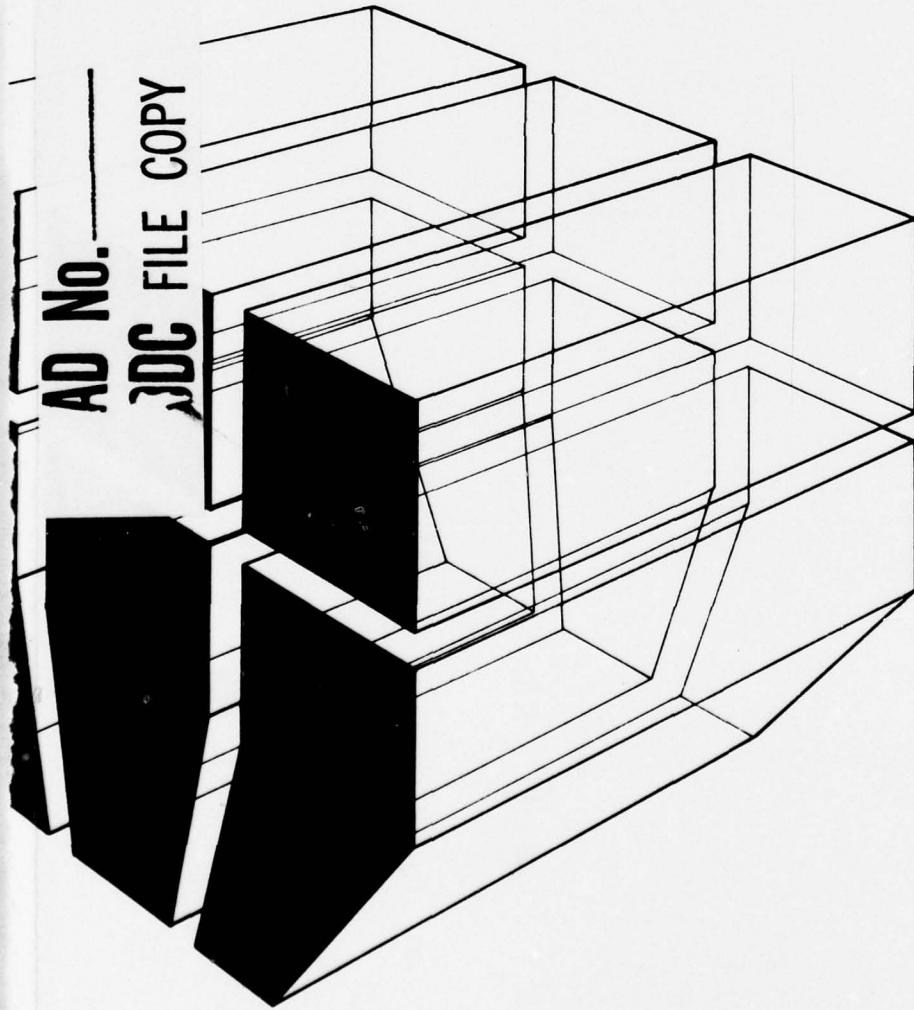
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TECHNICAL REPORT M-233
April 1978

CONSTRUCTION WITH FIELD MOLDABLE
POLYURETHANE FOAM BLOCKS

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by
Alvin Smith



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents the results of an investigation of the use of polyurethane foam for expedient shelters in the theater of operations (TO). The evaluation showed that polyurethane foam can bring about significant savings in material shipping weight and volume, construction time, and required personnel skill levels, compared to present base development materials. A model structure was erected in which the wall components were building blocks molded from a low density foam. The building blocks can be fabricated in the			

Block 20 continued.

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field by low-skill personnel using simple molds and mixing equipment. The blocks are equal in size to two regular 8 X 8 X 16 in. (203 X 203 X 406 mm) concrete blocks and weigh about 4 lb (1.8 kg) each. They can be rapidly assembled into a wall using an adhesive applied by caulking gun. Conventional foundation, floor, and roofing systems can be used with this wall system.

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FOREWORD

This investigation was conducted for the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE), under RDT&E Program 6.27.02, Project 4A762619AT41, "Research for Base Development in the Theater of Operations"; Task 08, "Base Development Design and Construction"; Work Unit 002, "Foam Material Applications in Theater of Operations Construction." The OCE Technical Monitor is Mr. E. McWhite.

The work was performed by the Engineering and Materials Division (EM), U. S. Army Construction Engineering Research Laboratory (CERL). Laboratory and developmental work were done at CERL.

Appreciation is expressed to Mr. Harvey Barrett, formerly of CERL, for his contribution of many innovative methods of accomplishing the tasks involved in the study.

COL J. E. Hays is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director. Dr. G. R. Williamson is Chief of EM.

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CONTENTS

DD FORM 1473	1
FOREWORD	3
LIST OF TABLES AND FIGURES	5
1 INTRODUCTION	7
Background	
Objective	
Approach	
Scope	
Mode of Technology Transfer	
2 DEVELOPMENT	8
Consideration of Practicality	
Fire Considerations	
3 FABRICATION AND EVALUATION	9
Mold Design	
Molding of Foam Blocks	
Building With Foam Blocks	
Evaluation of Foam Blocks	
4 CONCLUSIONS AND RECOMMENDATIONS	11
FIGURES AND TABLES	12
APPENDIX: Compression and Diagonal Tension Test Results	39
DISTRIBUTION	

TABLES

Number	Page
1 Standard and Lightweight Concrete Block and Foam Block Specifications	37
2 Total Load on Load-Carrying Periphery Walls of Typical AFCS and Wood Frame Buildings	38
A1 Results of Compression Tests on Foam Blocks	46
A2 Typical Load-Deformation Data for Normal Loading	46
A3 Typical Load-Deformation Data for Side Loading	46
A4 Standard and Lightweight Concrete Block Compared to Foam Block	47
A5 Diagonal Tension Test on Foam Block Panels	48

FIGURES

Number	Page
1 Mold for Forming Foam Blocks	12
2 Disassembled Mold	13
3 Application of Mold Release Agent	13
4 Assembling of Mold	15
5 Mold Sides and Inserts	16
6 Placing Top on Mold	17
7 Mold Completely Assembled	17
8 Removal of Liquid Component From 55-Gallon Drum	18
9 Weighing of Material	18
10 Mixer	19
11 Mixing of Foam Components	19
12 Pouring Mixture Into Mold	20
13 Mold Top Removed to Show Foam Block	20
14 Removal From Mold	21
15 Foam Blocks With Inserts in Place	22
16 Removal of Inserts	23
17 Completed Block	24
18 Reassembled Mold Ready for Next Cycle	25
19 Flow Diagram of Molding Process	25
20 Stack of Molded Blocks	26

FIGURES (cont'd)

Number	Page
21 First Course of Blocks in Model Buildings	26
22 Application of Adhesive	27
23 Additional Courses of Blocks	27
24 Lightweight Blocks	28
25 Plumb Check	28
26 Completed Wall System	29
27 Volume Expansion Is Impressive	29
28 Concrete Blocks Shown Weigh as Much as the Two Drums of Material or All of the Foam Blocks in the Model Structure	30
29 Foundation and Floor Slab for Model Structure	30
30 Transporting a Wall Section	31
31 Placing Wall Section on Slab	31
32 Interlocking Wall Sections at Corner	32
33 Three Wall Sections in Place	32
34 End Wall With Door Opening	33
35 Eye-Bolt Anchor in Foundation	33
36 Cable Attached to Eye Bolt Anchor	34
37 Top Plate With Anchor Bolts	34
38 Top Plate in Place	35
39 Structure Ready for Roof System	35
40 Roof System in Place	36
41 Application of Various Finish Materials	36
A1 Foam Block Specifications	40
A2 Typical Load Deformation Curve for a Foam Block Loaded Normal to X Axis	41
A3 Typical Load Deformation Curve for a Block Loaded From the Side	42
A4 Diagonal Tension Test of Dot Bonded Wall Section (Diagonal Tension Specimen #1 DB).	42
A5 Diagonal Tension Test of Dot Bonded Wall Section (Diagonal Tension Specimen #2 DB).	43
A6 Diagonal Tension Test of Full Bonded Wall Section (Diagonal Tension Specimen #1 FB).	44
A7 Diagonal Tension Test of Full Bonded Wall Section (Diagonal Tension Specimen #2 FB).	45

CONSTRUCTION WITH FIELD MOLDABLE POLYURETHANE FOAM BLOCKS

1 INTRODUCTION

Background

The requirement for rapidly erectable shelters in building a theater of operations (TO) base has been recognized for many years. A fast build-up of personnel to support and conduct military activity creates the need for a rapid means of housing the personnel.

Foamed plastic materials can be used to augment the present methods of TO base development. Foam components can be shipped in a dense (approximately 70 lb/cu ft [1100 kg/m³], sp gr 1.12) form and molded into a low density foam (approximately 4 lb/cu ft [64 kg/m³] sp gr 0.06) material having usable structural properties. The conversion time from the two liquid components to foam is short—about 2 minutes—and the time from the introduction of the mixture into the mold until the block can be used is only about 30 minutes.

Objective

The objective of this study was to evaluate use of foamed plastic as a construction material in expedient shelters (field-formed foam block structures) to provide significant improvements in logistics (weight and volume) and reductions in labor skills and man-hours required for TO base development.

Approach

A variety of possible uses of foamed plastics in the TO were identified and investigated. Uses which applied the structural qualities of the materials were considered primarily. Other properties, such as the ability to seal and insulate, were taken into account but were given lower priority than structural applications. Since the strength of foams is generally low (20 to 50 psi [138 to 345 kN/m²]), their use in conventional structural applications is limited to situations in which applied forces are low and well distributed.

Methods for converting the liquid chemical components of the foam systems into usable building blocks were studied. Block molds were designed and

fabricated. Enough foam blocks were molded to study the molding procedures and to build a small model structure (10 ft, 8 in. wide by 14 ft long [3.25 m by 4.27 m]) having a conventional foundation, concrete floor, and pitched roof system.

Scope

This study was restricted to the use of polyurethane foam, which provides the greatest potential for meeting TO use criteria of low shipping volume and weight, easy conversion to foam, and low skill level requirements for both conversion and use of the fabricated material. Polystyrene and polyethylene foams were considered, but they do not meet the logistical requirements.¹ Both materials are manufactured in processes which use elaborate equipment and require a complex plant. They are low density at the end of processing and would occupy a very large shipping volume.

Mode of Technology Transfer

The results of this study will impact on the following technical manuals:

- TM 5-301—*Army Facilities Component System - Planning*
- TM 5-302-a. *Army Facilities Component System - Designs, Vol I*
- TM 5-302-b. *Army Facilities Component System - Designs, Vol II*
- TM 5-303—*Army Facilities Component System Logistics Data and Bills of Materials*
- TM 5-349—*Arctic Construction*
- TM 5-852-9—*Arctic and Sub-Arctic Construction - Building*
- TM 5-882-2—*Engineering and Design - Structure Design - Emergency Construction*

Training may be implemented by appropriate entries in ARTEP 115, Engineer Combat Battalion (Heavy). The construction method and materials described herein offer an alternative to temporary shelters described in FM 20-15, *Tents, Pole and Frame Supported*.

¹ Alvin Smith, *Feasibility of Structural Foam/Concrete Building for Theater of Operations Use*, Technical Report M-231 (U. S. Army Construction Engineering Research Laboratory [CERL], March 1978).

2 DEVELOPMENT

Consideration of Practicality

Low-density plastic foams have been shown to have usable structural properties.² Many structural shapes have been investigated and means of forming these shapes have been reported.³

Polyurethane foams, which can be shipped as liquid components in standard 55-gal (241.2- ℓ) steel drums weighing about 500 lb (225 kg), can be shaped using simple molds and easy-to-operate scales and mixers. The skills for molding these foams can be learned in a short instruction and practice period of about 4 hours. The appendix contains data on some of the technical aspects of polyurethane foams.

Field conditions pose no significant problems in molding polyurethane foam. A sheltered area such as a general purpose medium or maintenance tent, which can be maintained at a temperature of about 50°F (10°C) or above, can serve as a molding shop. When outside temperatures are lower than 50°F (10°C), heat can be added by a unit such as the Herman-Nelson heater.

Molds for shaping foam should be made of metal, preferably aluminum. The molds can be prefabricated and stored until ready for use. Release agents such as wax or light oil are required to allow easy removal of a molded part. Molds must be tightly constructed to prevent leakage and should be equipped with small vents in the top to allow air to escape as the foam expands and fills the mold.

A means of measuring the liquid components of the foam system is required. Although the materials may be measured by volume, scales are preferred. An accuracy of about ± 1 percent in measuring each of the two liquids is desirable; greater deviations can be tolerated but the quality of the foam and its physical properties will not be optimum.

Mixing equipment can be as simple as a stirring paddle operated by hand or as sophisticated as a foam metering and mixing machine. Mechanical mixing should be used for best results. An electric drill motor fitted with a high shear mixing blade works very well and is appropriate for field use. Mixing containers should be sturdy and preferably made of polyethylene since they can be cleaned and reused numerous times.

Common hand tools such as wrenches, plastic- or leather-faced mallets, and putty knives are the only tools required to operate the molding facility.

Depending on the required hourly or daily block output, the number of operating personnel will vary. In general, an individual can handle two molds. Output can be estimated by the time the foam material must remain in the mold. The foam systems most suited to block production require about 10 minutes in the mold. In a hypothetical situation in which 12 molds are used, for example, the rate of production would be about 1 block per minute. For blocks of the size used in this study (8 in. wide \times 8 in. high \times 32 in. long [203 mm \times 203 mm \times 812 mm]), which are about twice the size of a typical 8-in. (203-mm) concrete block, this rate would generate enough blocks in 24 hours to produce 312 lin ft (95 m) of wall 8 ft (2.4 m) high. The walls of a single-story building with about 5600 sq ft (520 m²) of floor space could thus be produced from a small facility in a 24-hour work day.

Only 12 drums (6000 lb [2727 kg]) of foam materials are required to produce the blocks in the foregoing example. Placed on shipping pallets, these drums would occupy 192 cu ft (5.4 m³). Enough concrete blocks weighing about 40 lb (18 kg) each to provide the same amount of wall system would weigh 115,200 lb (52,364 kg) and would occupy 1700 cu ft (48 m³). Thus, a potential shipment weight savings of about 95 percent and a shipment volume savings of about 88 percent can be realized by producing foam blocks on-site rather than shipping concrete blocks to the base development area.

Constructing a building using foam blocks is easy and rapid. The blocks can be used immediately after they are removed from the mold. A simple floating type of foundation can be used since the dead load of the building is significantly lower than that of a comparable concrete block building. The foam blocks can be bonded together by a structural adhesive available in caulking gun tubes or in bulk containers. The adhesive, which does not require mixing, sets slowly

²Feasibility of Structural Foam/Concrete Building for Theater of Operations Use; and Alvin Smith, Dome Shelter Construction with Polyurethane Foam, Technical Report M-225/ADA044992 (CERL, August 1977).

³Stephen C. A. Paraskevopoulos, Architectural Research on Structural Potential of Foamed Plastics for Housing in Underdeveloped Areas (Architectural Research Laboratory, University of Michigan, 1965).

enough to allow adjustments in level and plumb alignments within 2 to 4 hours after placement. Inexperienced personnel can erect the wall sections since mortar joints are not used and the foam blocks will be of uniform dimensions.

The roof system, which can be the engineered truss type with appropriate decking and weatherproof membrane, must be secured to the foundation system by tie bars, cables, or columns; attachment to the foam block alone is not sufficient. The spacing and sizing of the attachment member will depend on the size of the building and the live loads anticipated.

Fire Considerations

An exterior and interior fireproof or fire-resistive coating should be applied to the foam blocks.

The flammability of foamed plastics has been the object of much discussion and research in the past few years. The extremely rapid-burning and highly toxic combustion products have caused a great deal of concern about the use of foams in habitable structures.

Organic foams will burn. The rates of burning and the flame spread depend on many factors, whose interdependency makes it impossible to cite examples of foam's performance in fires, or to predict exact performance of any particular foam.

Combustion products, whether from complete or incomplete oxidation of the molecular fragments pyrolyzed from the polymer, may be toxic. As in any fire, the most serious component is usually carbon monoxide. Other toxic gases such as hydrogen cyanide may be present, but the amount is typically about the same as or less than would be formed from wood, nylon, or wool burning under the same conditions. Compounding the problem of possible toxic products is the smoke generated by burning or partially burning foams. Dense, black, sooty smoke capable of obscuring visibility can be reduced by limiting the foam's involvement in a fire; this can be done by applying an effective flame-resistant coating or by using plaster or gypsum board.

Generally, foams burn more easily than their solid polymer counterparts because of the greatly increased surface area presented for thermal decomposition of the material. In order to bond the cementitious material to the foam, it is recommended that a 1-in. (25-mm) hexagonal wire mesh be stapled to the foam surface before troweling or brushing cementitious

material to the surface. It is therefore extremely important to apply protective coatings to exposed foam very soon after the foam application is completed, preferably before other finishing operations commence. A coating which impedes the thermal attack on the foam will usually greatly reduce flame spread. Cementitious materials (cement, lime, sand, and water) brushed or troweled directly onto the surface of the foam have been found effective in limiting fire involvement.⁴

The relatively small sizes of TO structures facilitate quick exit in the event of a fire. Personnel would thus be afforded an additional protection by short potential exposure time.

In summary, although foamed plastics generally will burn, effective fire/flame-resistant coatings can be made and applied in the TO from materials that are normally available there. These coatings will afford adequate protection to personnel in the event of fire.

3 FABRICATION AND EVALUATION

Mold Design

A block size of 8 in. wide X 8 in. high X 32 in. long (203 mm X 203 mm X 812 mm) was selected for this study to provide a module which would be convenient to fabricate and versatile in construction use. A mold for forming the blocks was designed and constructed. It is an aluminum box with sides interlocking by means of grooves into the top and bottom. The end plates similarly interlock into both the sides and top and bottom. The faces of the mold were made of 3/8-in. (9.5-mm) 6061-T6 aluminum plate. Four symmetrically spaced cylindrical inserts of the 6-in. (152-mm) OD drawn aluminum tube were included in the design to reduce the volume in the mold. A 1/2-degree taper was machined on the length of each insert tube to facilitate its removal from the molded foam part. The inserts were spaced by 1/4-in. (6.4-mm) thick spacers bolted to the bottom of the mold. The top and bottom of the mold were secured to each other by 1/2-in. (13-mm) diameter threaded rods. Because of the interlocking features of the mold parts, once the top and bottom were held together, the mold could withstand the

⁴ Alvin Smith, *Fire/Flammability Test of Polyurethane Foams and Protective Coatings*, Technical Report M-129/ADA028386 (CERL, July 1976).

internal pressure developed by the foam. Air vents $1/16$ in. (2 mm) in diameter were provided at each corner of the top plate. A centrally located fill hole $1\frac{1}{4}$ in. (32 mm) in diameter was placed in the top plate. A cap to seal the fill hole after introduction of the foam mixture was also provided. This arrangement allowed complete assembly of the mold prior to mixing or pouring the foamable material into it. The complete mold weighed 80 lb (36 kg). Fabrication of several molds would require about 4 man-hours of machinist labor in a machine shop. Figure 1 is a drawing of the mold parts and Figures 2 through 7 show the completed mold in various stages of assembly. The mold was prepared for the block molding operation by coating all parts of it with a paste wax (Johnson's Traffic Wax).

Molding of Foam Blocks

The volume of the mold was calculated to be 2408 cu in. (0.034 m^3) minus the four inserts of 226 cu in. (0.003 m^3) each, for a total volume of 1144 cu in. (0.018 m^3) or 0.66 cu ft (0.019 m^3).

The unrestricted "free" rise density of the foam selected for use (the Freeman Chemical Co., Chempol 32-1730/32-1601 system) was 2.5 lb per cu ft (pcf) (40 kg/m^3). To obtain high quality molded parts, especially where relatively thin sections are involved, it is necessary to "pack" the mold and achieve about 6 pcf (96.1 kg/m^3) molded density from the lower density foam system.

Separate containers were filled with 2.2 lb (1 kg) of each component of the foam system (Figures 8 and 9). One component was then immediately poured into the other and the mixture was blended by a Jiffy* mixer consisting of three 2-in. (50.8-mm) blades set about 1 in. (25.4 mm) apart on a 3/8-in. (9.5-mm) diameter shaft (Figure 10). The mixer was affixed in a floor-type drill press which turned it at about 2000 rpm (Figure 11). The mixing operation required 30 seconds.

The mixture was introduced into the mold through the fill hole (Figure 12). The foam mixture began reacting and rising immediately, and within 2 minutes had completely filled the mold.

The foam blocks remained in the mold for 10 minutes to allow enough curing to maintain dimensional stability.

Removal of the block from the mold required loosening the rods, securing the top and bottom, rotating them out of the way, and removing the mold top (Figure 13). The side plates were then removed, followed by the end plates (Figure 14). The block and inserts were then separated from the bottom of the mold (Figure 15). The inserts were pressed from the block (Figure 16), and minor post-molding finish work was performed. The block was then ready for use in construction (Figure 17). The mold was cleaned, re-waxed, and reassembled for the next molding cycle (Figure 18). Figure 19 is a flow chart of the molding operation.

A molding facility equipped with 12 molds and necessary tables, scales, and mixing equipment should be manned as follows for each shift:

Supervisor	1
Weigh/mix operator	1
Mold handler	6

The weigh/mix operator and mold handlers can rotate jobs periodically at the supervisor's discretion. Having six mold handlers should allow adequate time for continuous operation if break periods are staggered.

A continuous 24-hour operation is desirable for maximum efficiency. The output of such a facility should be about 480 blocks per 8-hour shift, or 1440 blocks per 24-hour day. The material inflow for a 24-hour operation would be about three pallets of four drums each. The block outflow should be adequate (as described) for the exterior walls of a 56×100 ft ($17\text{ m} \times 30.5\text{ m}$) single-story building, with a floor area of 5600 sq ft (520 m^2).

Figure 20 shows the stacks of blocks molded from the contents of the two drums shown.

Building With Foam Blocks

Erecting a wall system using foam blocks is simple and fast. The foundation must be satisfactory in terms of strength and levelness. Guide strings or lines are used to outline the first course of blocks, then doorways are set (Figure 21) and the first course of blocks laid. Since the blocks are dimensionally uniform, there is no problem of aligning subsequent courses. The blocks are banded together with a caulking-gun-applied adhesive such as Styrobond* (Figure 22), which re-

*Registered trademark.

*Registered trademark.

mains pliable for a few hours after application and allows minor adjustments in alignment as the work progresses (Figure 23). The blocks are lightweight—about 4 lb (1.8 kg)—and are easily handled (Figure 24). The wall should be checked periodically to verify plumb and level conditions (Figure 25). Additional courses are laid until the required wall height is attained (Figure 26). The model building wall system took two individuals less than 4 hours to complete.

Figure 27 shows the room (10 ft, 8 in. \times 14 ft [3.25 m \times 4.27 m]) built of the blocks molded from the raw materials in the two drums shown. Figure 28 is a good illustration of the weight and volume savings realized by the use of foam blocks. The concrete blocks shown weigh the same as two full drums of material and occupy almost as much volume. As can be seen, many times the number of concrete blocks shown would be required to build a room the size of the one built of foam blocks.

The initial construction described above was performed in the laboratory. A foundation and slab floor were prepared outside for permanent erection of the building (Figure 29). Eye bolts were embedded in the concrete for use as anchors. The four walls of the structure were easily transported to the erection site (Figures 30 and 31). (In the laboratory fabrication, adhesive had not been applied to the area of overlap at the corners as shown in Figures 32 through 34.) Because of the low weight and ease of transporting the wall sections, modular wall sections could be prefabricated in the field and transported to the building site for erection.

The walls were anchored to the foundation by placing 1/8-in. (3.2-mm) steel cables between the eye bolts in the foundation (Figures 35 through 39) and eye bolts through the wood top plates (1 1/2 \times 9 1/2 in. [38 \times 241 mm]). The cables were tensioned by tightening the top eyebolt.

The roof consisted of pre-built trusses spaced on 24-in. (610-mm) centers. The trusses were designed for adequate roof support for the structure. An overhang of 24 in. (610 mm) was provided on all sides of the structure. A plywood deck was installed on the trusses, and roofing felt (45 lb) was used as the waterproof membrane (Figure 40).

Various finish materials were applied to different parts of the building wall system to demonstrate the capability of using those finishes in conjunction with the foam block construction. Figure 41 shows the plan of the finish work. All the finish materials were easy to apply.

Evaluation of Foam Blocks

Foam block sections and wall sections were subjected to compression and diagonal tension loading, respectively. The results are presented in the appendix and summarized in Table 1.

The compressive strength values agreed with expected results, but the diagonal tension tests resulted in failure of the bonding material in both test configurations described in the appendix. Other adhesive materials, such as epoxies, should be used for wall construction if large racking loads are likely. Although less convenient to use, the higher bonding strength cements typically cause failure within the foam. This kind of failure represents the highest functional strength of the foam block wall system. The tensile strength of polyurethane foam is usually about the same as the compressive strength, and this value may be used in design when high bonding strength cements are used.

Since the compressive and diagonal tension tests indicate that foam blocks have significantly lower strengths than the conventional concrete blocks (Table 2), the roof loads (live plus dead) on load-bearing periphery walls of typical AFCS wood frame buildings were computed. Table 2 indicates that the resulting roof loads are all significantly below the load capacity of the foam block wall system. Thus, the foam blocks are strong enough to be load-bearing walls for most AFCS-type, single-story wood frame structures.

4 CONCLUSIONS AND RECOMMENDATIONS

This study has demonstrated the following advantages in the use of polyurethane foam block molding and construction in the TO:

1. Low shipping volume and weight.
2. Easy conversion to useful building blocks by unskilled personnel using simple molds and equipment.
3. Potentially high production rates under field conditions.
4. Rapid construction.
5. Provision of conventional-looking, attractive wall systems for structures in the TO.

It is recommended that the foam block building system be considered for use in TO construction.

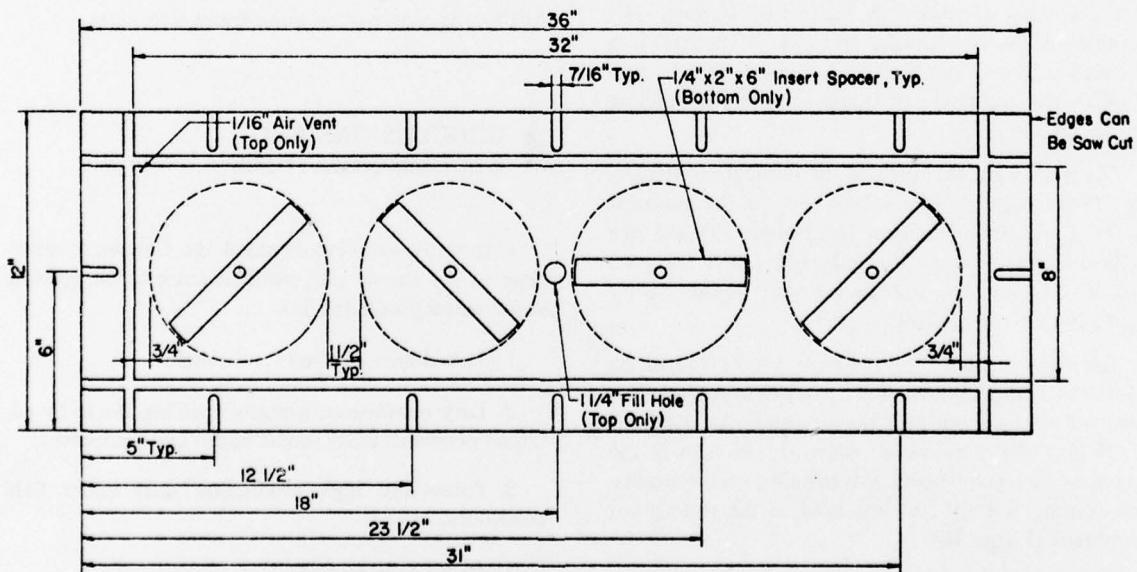
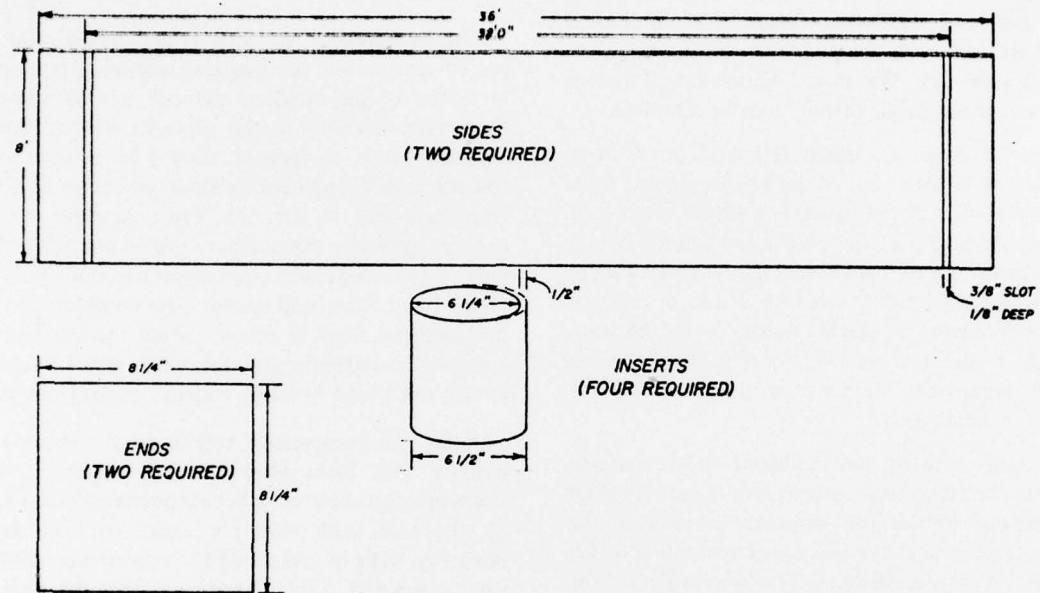


Figure 1. Mold for forming foam blocks. (Metric conversion factor: 1 in. = 25.4 mm.)

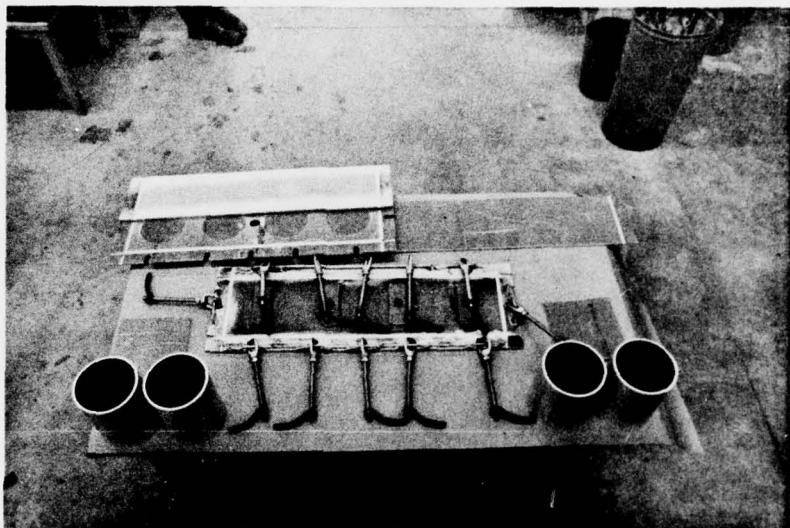


Figure 2. Disassembled mold.



a. Application to base of mold.

Figure 3. Application of mold release agent.



b. Insert assembly.



c. Inserts in place.

Figure 3 (con't)

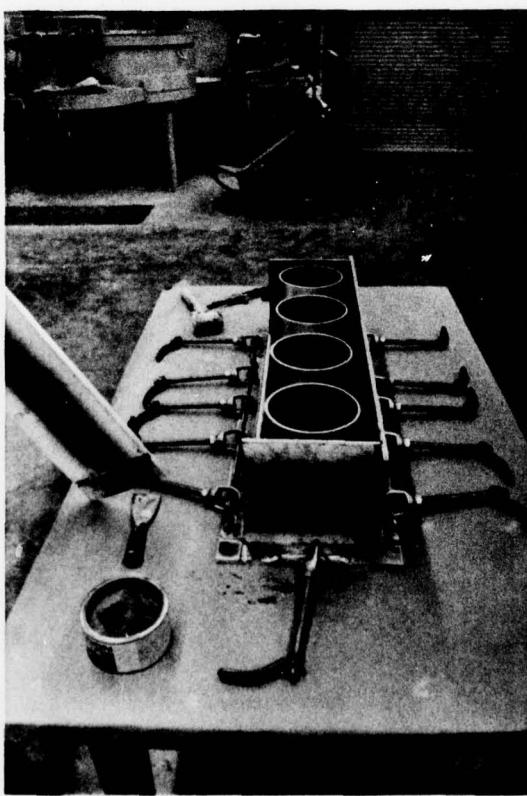


Figure 4. Assembling of mold.

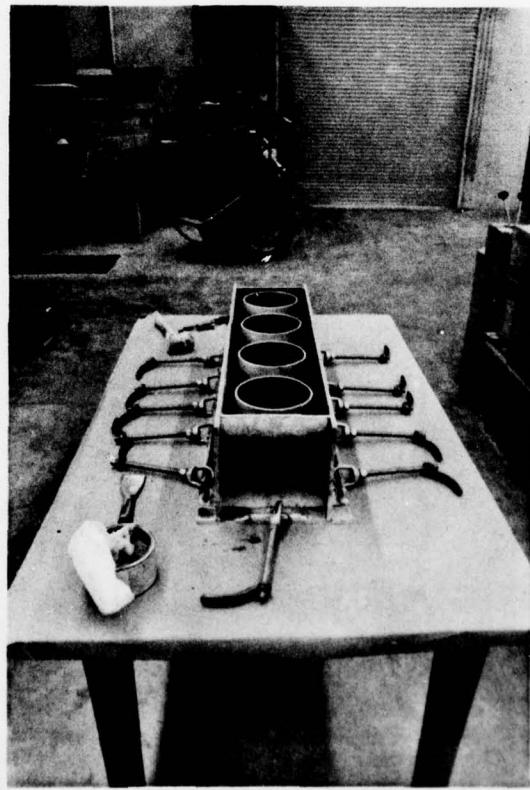


Figure 5. Mold sides and inserts.



Figure 6. Placing top on mold.

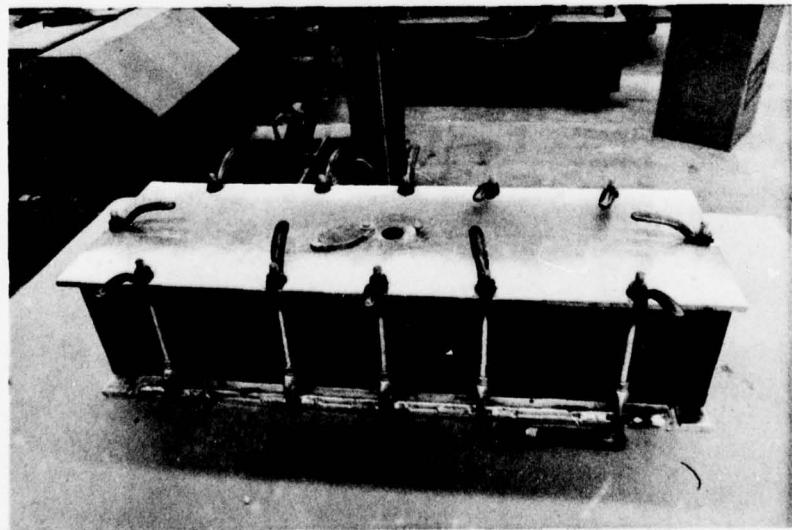


Figure 7. Mold completely assembled.



Figure 8. Removal of liquid component from 55-gal (241.2-l) drum.

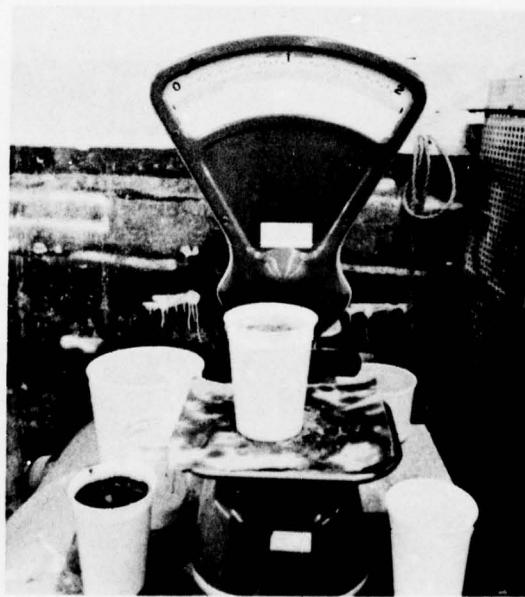


Figure 9. Weighing of material.

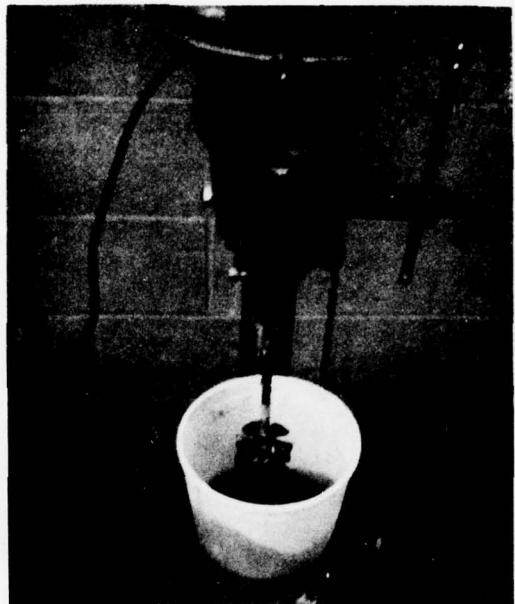


Figure 10. Mixer.



Figure 11. Mixing of foam components.

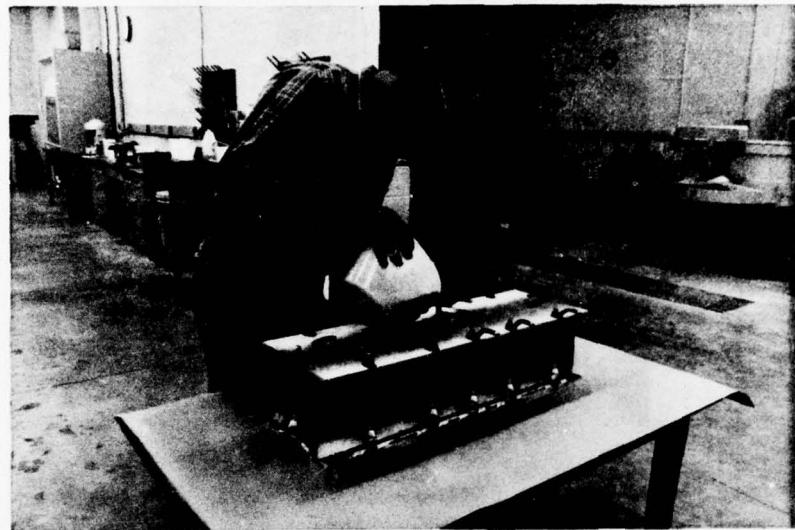


Figure 12. Pouring mixture into mold.

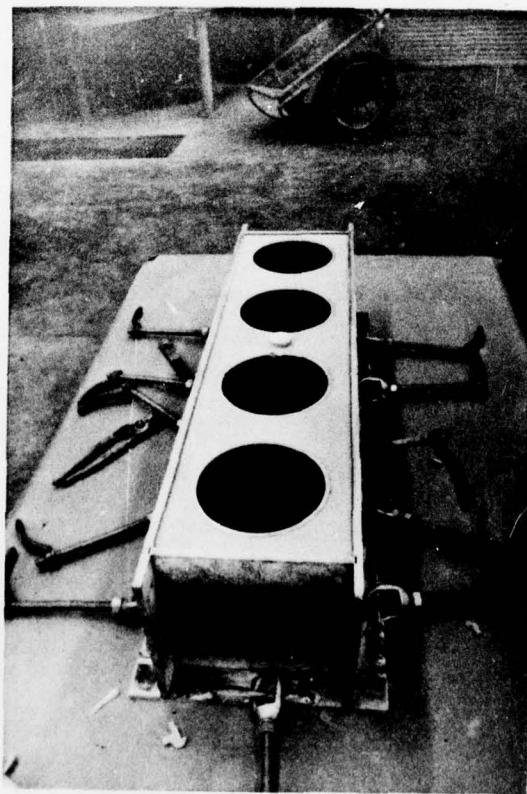
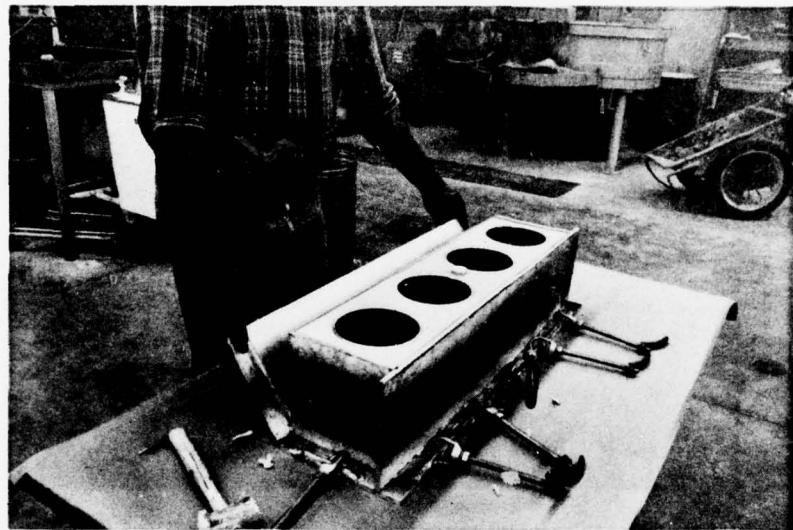


Figure 13. Top removed to show foam block.

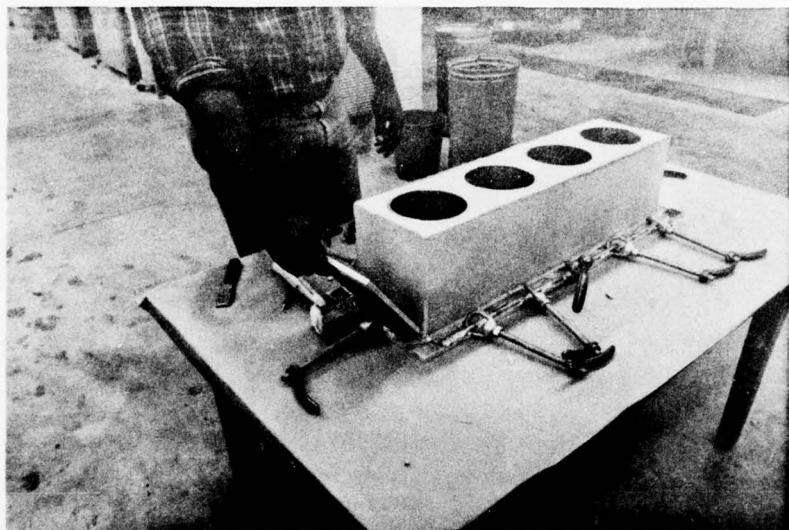


a.



b.

Figure 14. Removal from mold.



c.

Figure 14 (con't)

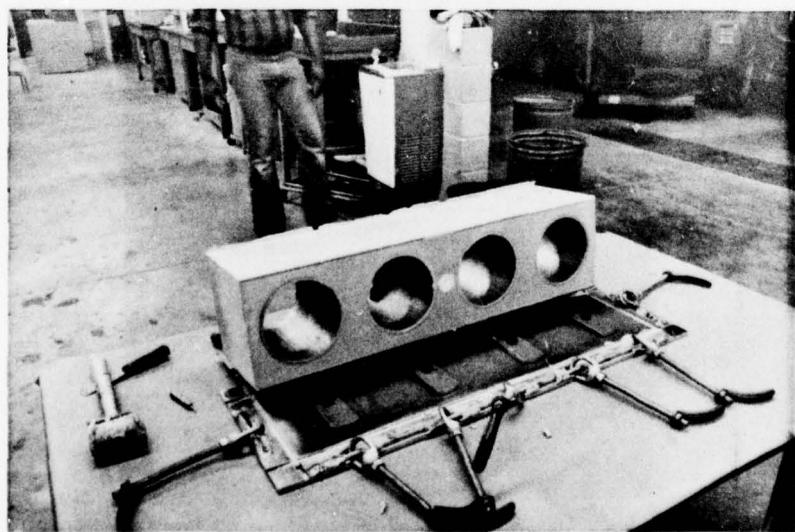


Figure 15. Foam block with inserts in place.



Figure 16. Removal of inserts.



Figure 17. Completed block.

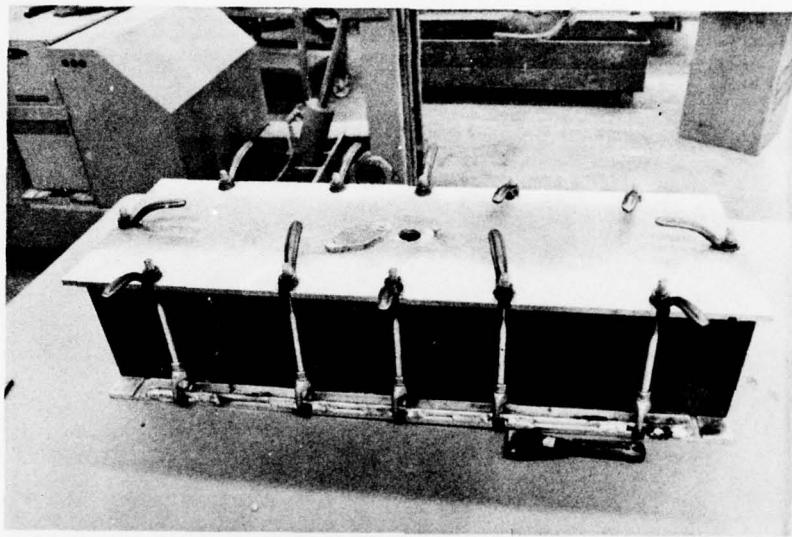


Figure 18. Reassembled mold ready for next cycle.

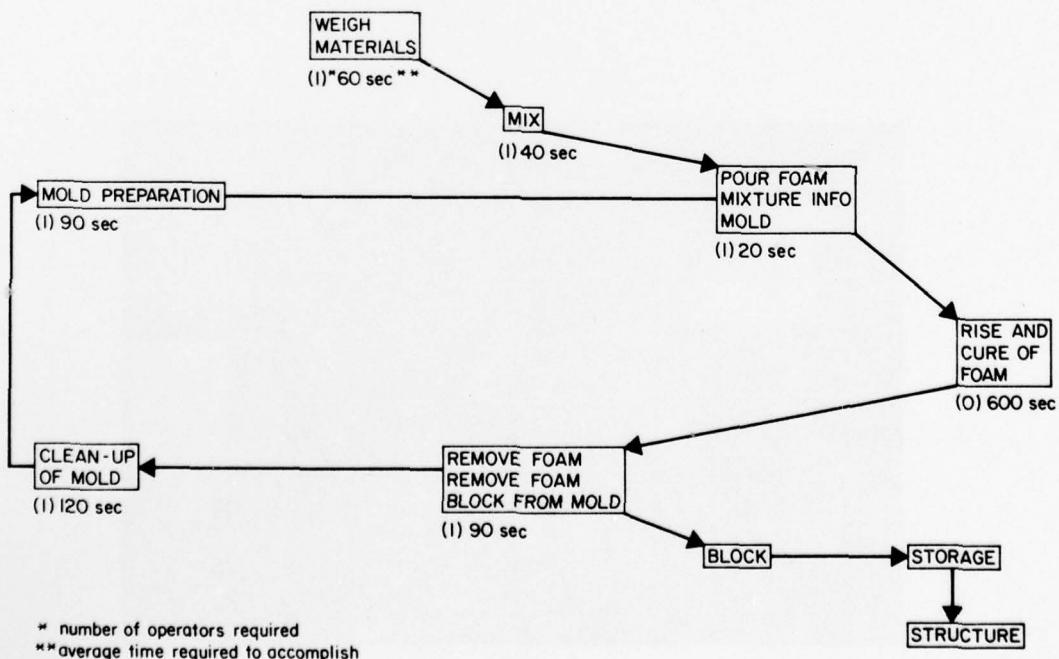


Figure 19. Flow diagram of molding process.



Figure 20. Stack of molded blocks (from the two drums shown).

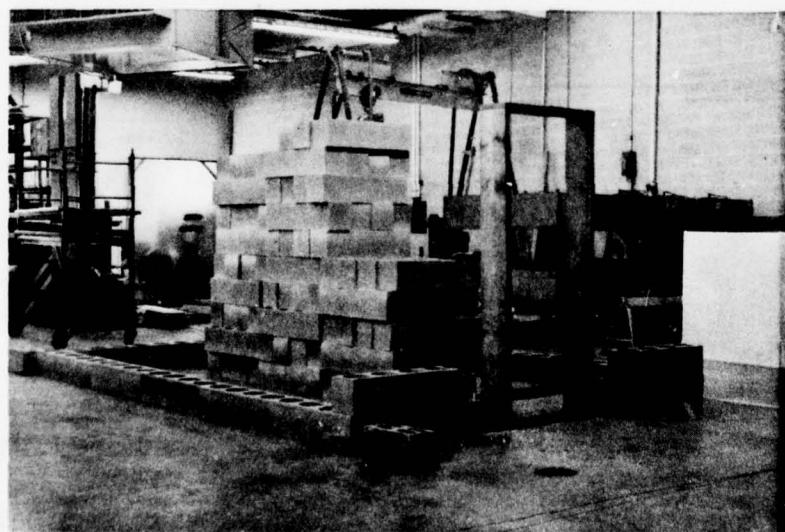


Figure 21. First course of blocks in model buildings.

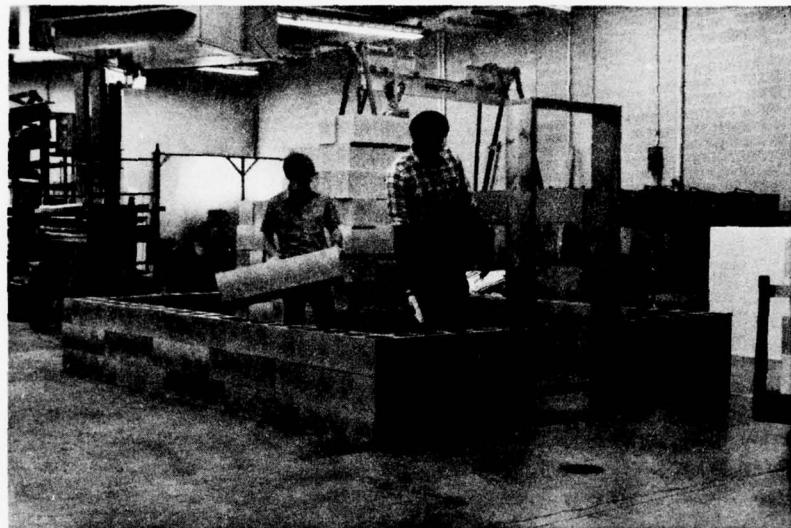


Figure 22. Application of adhesive.

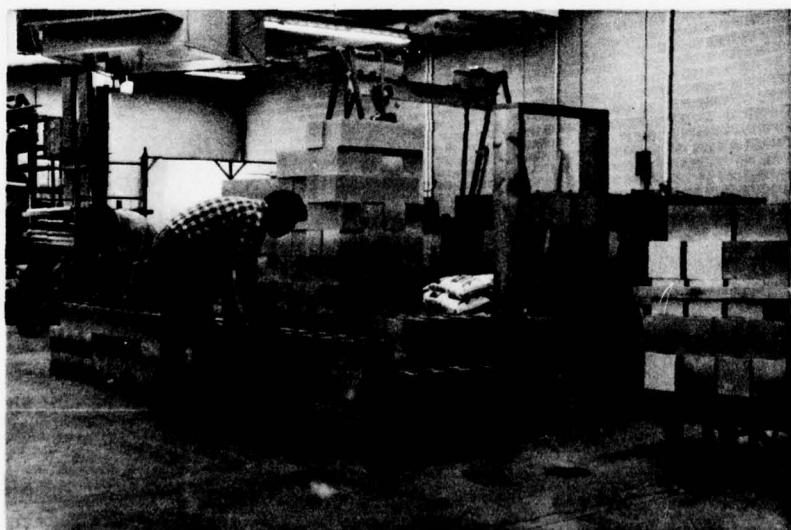


Figure 23. Additional courses of blocks.

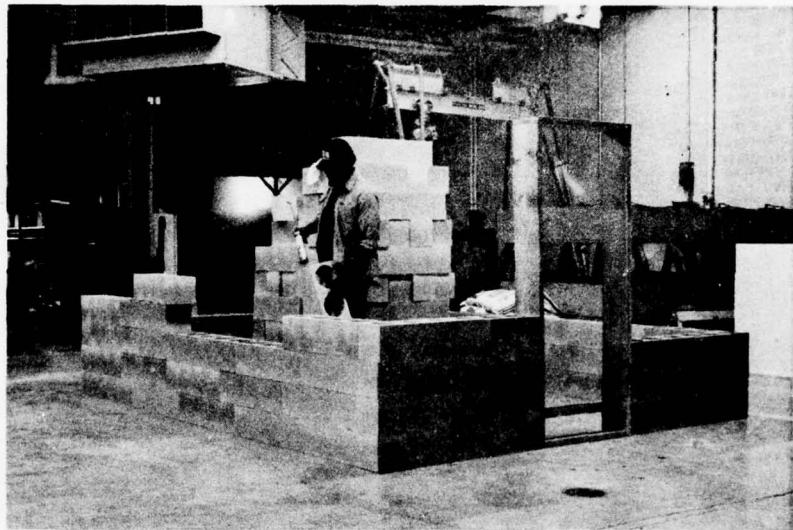


Figure 24. Lightweight blocks.

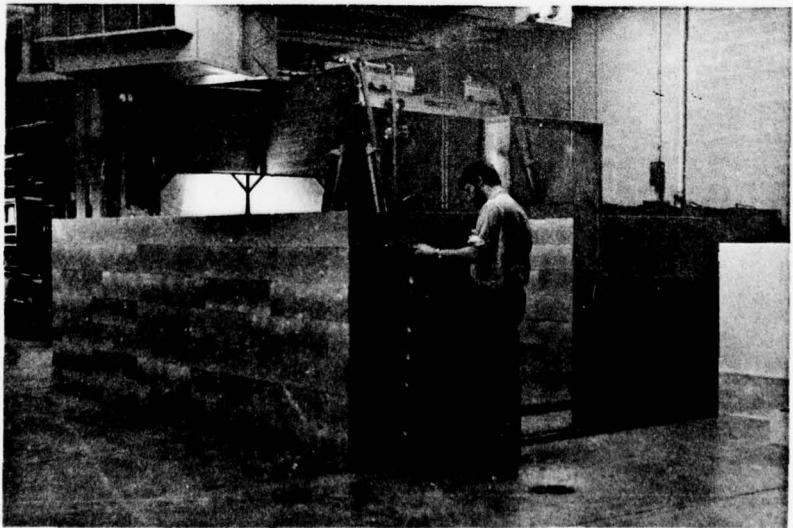


Figure 25. Plumb check.

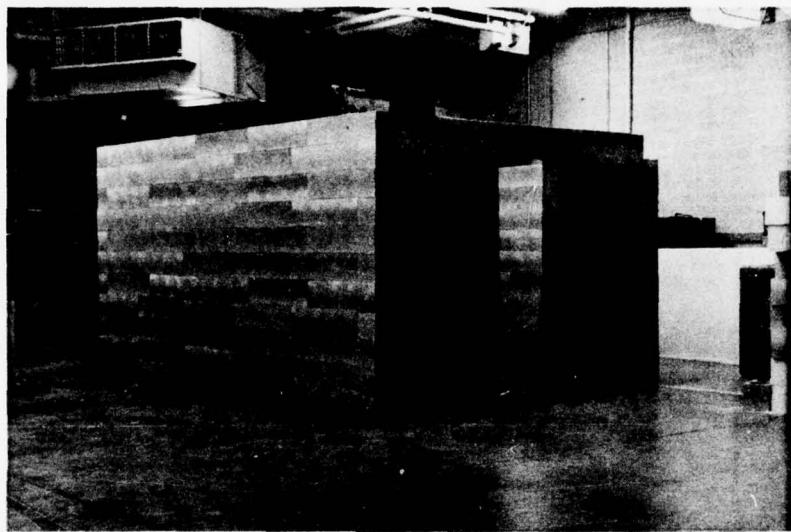


Figure 26. Completed wall system.

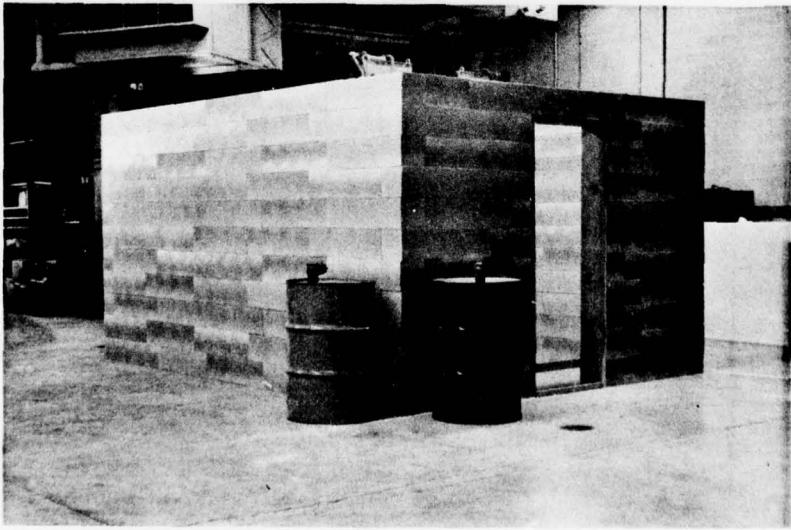


Figure 27. Volume expansion is impressive.

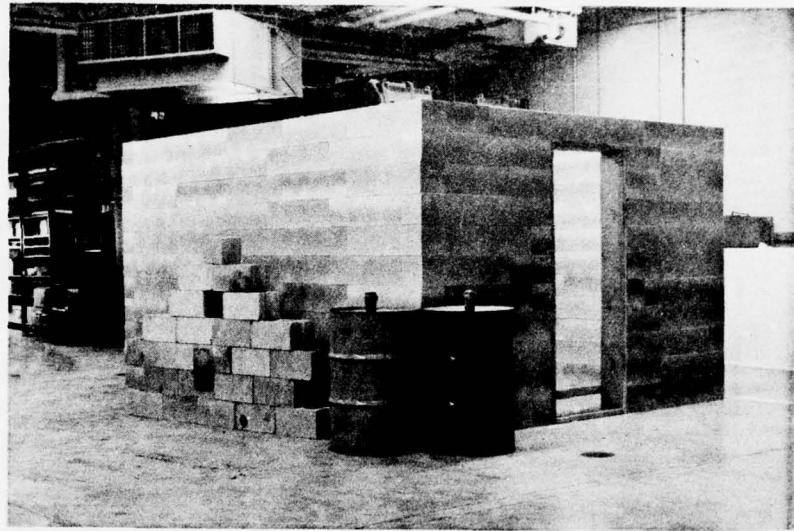


Figure 28. Concrete blocks shown weigh as much as the two drums of material or all of the foam blocks in the model structure.

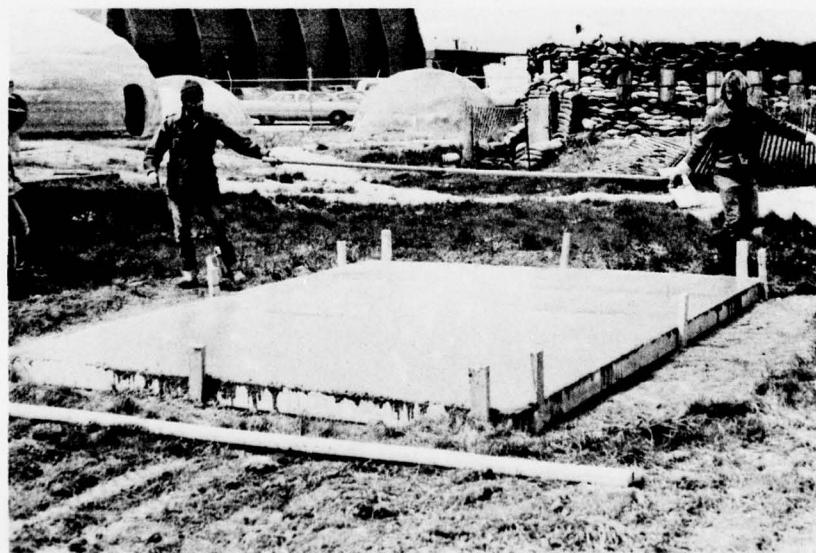


Figure 29. Foundation and floor slab for model structure.

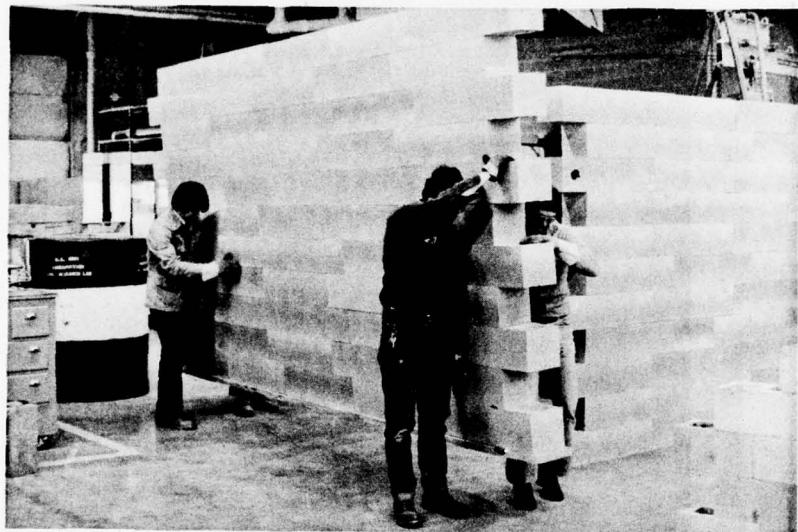


Figure 30. Transporting a wall section.

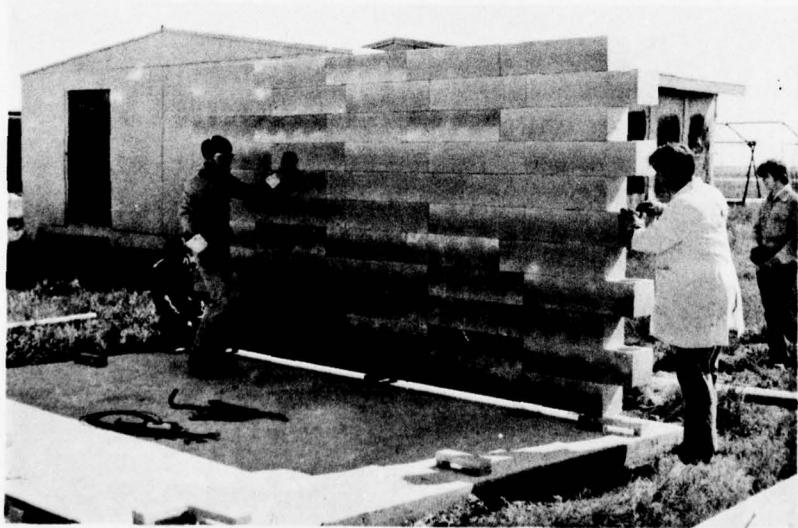


Figure 31. Placing wall section on slab.

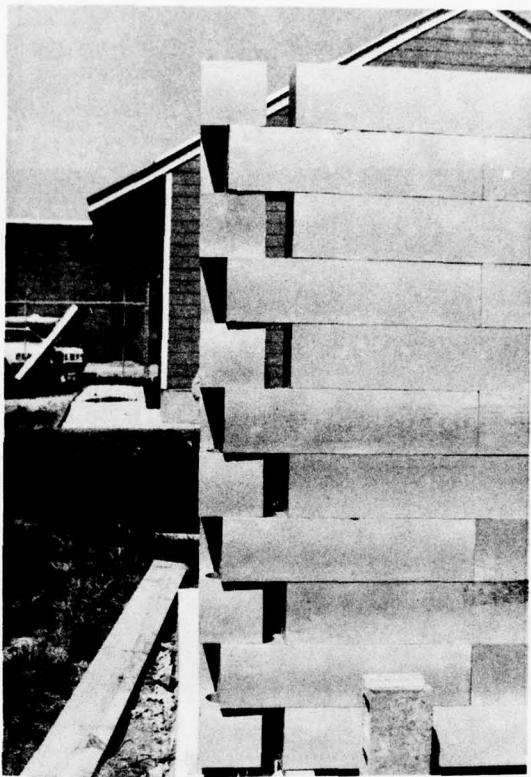


Figure 32. Interlocking wall sections at corner.

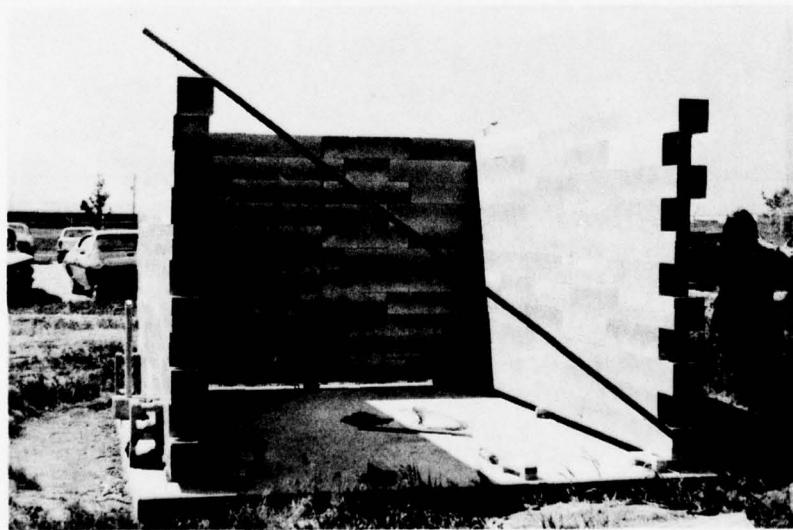


Figure 33. Three wall sections in place.



Figure 34. End wall with door opening.

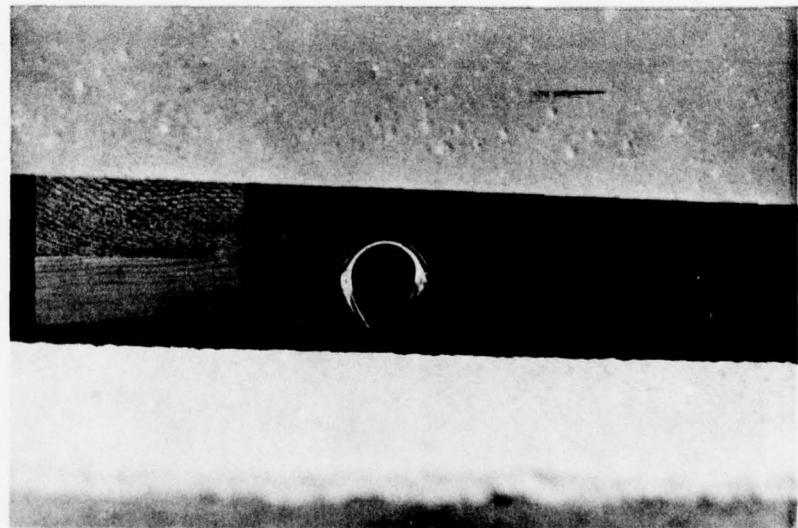


Figure 35. Eye-bolt anchor in foundation.

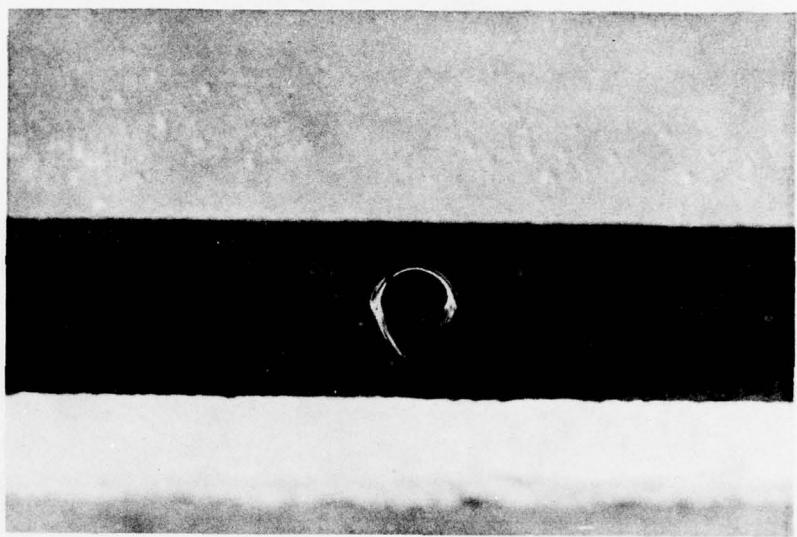


Figure 36. Cable attached to eye-bolt anchor.



Figure 37. Top plate with anchor bolts.

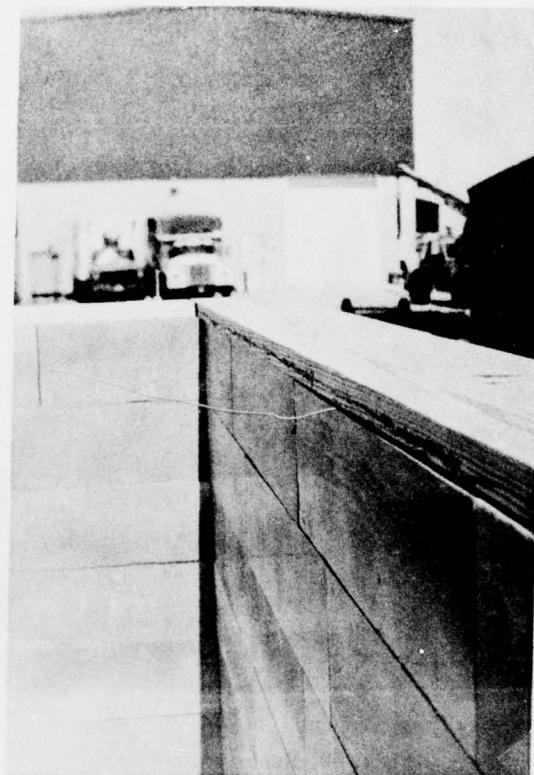


Figure 38. Top plate in place.

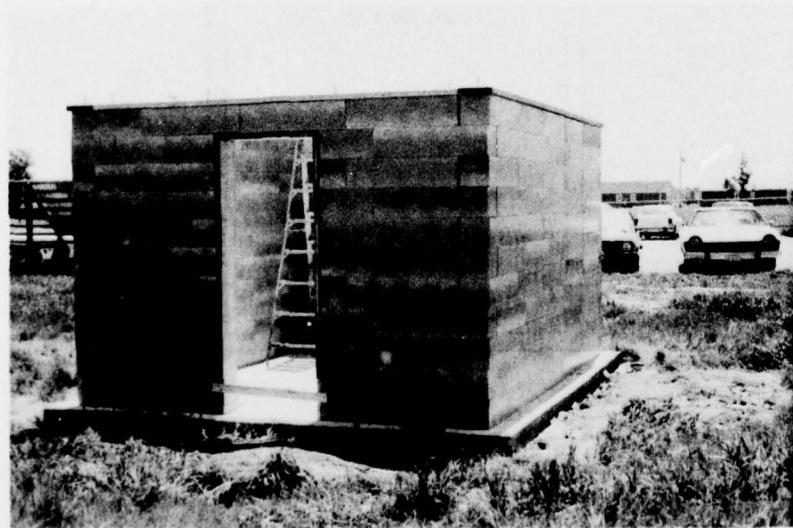


Figure 39. Structure ready for roof system.

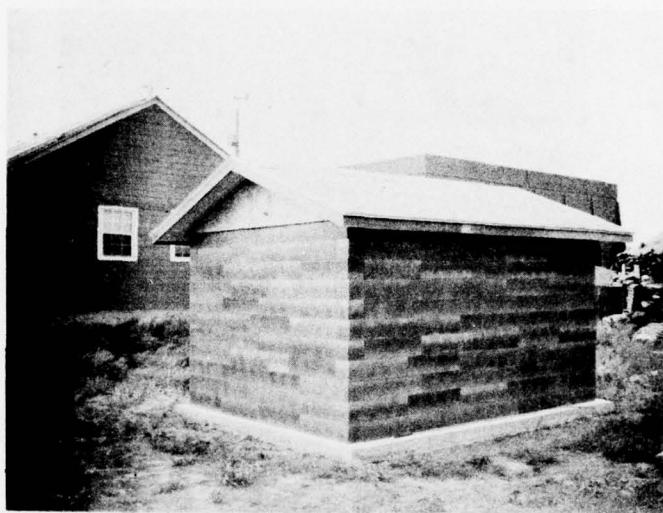
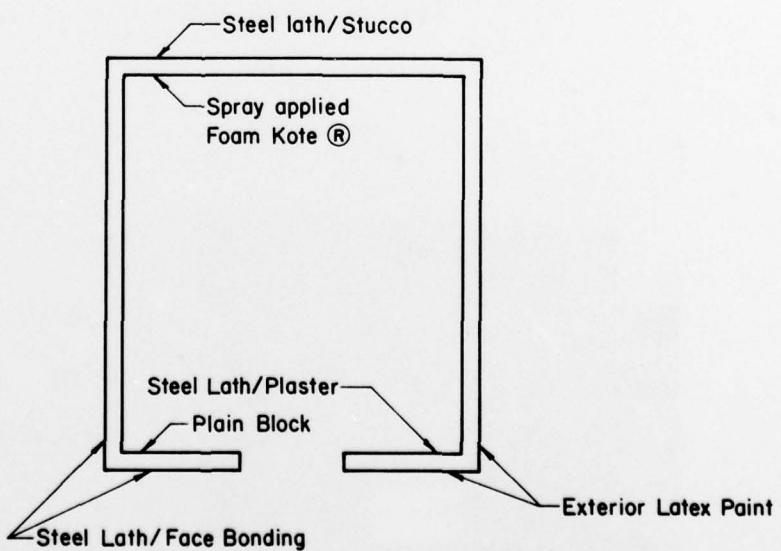


Figure 40. Roof system in place.



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Figure 41. Application of various finish materials.

Table 1
Standard and Lightweight Concrete Block and Foam Block Specifications

Specifications	Standard Concrete Block	Lightweight Concrete Block	Polyurethane Foam Block
Nominal size, in. (mm)	8 x 8 x 16 (203 x 203 x 406)	8 x 8 x 16 (203 x 203 x 406)	8 x 8 x 16 (203 x 203 x 406)
Actual size, in. (mm)	7.6 x 7.6 x 15.6 (193 x 193 x 396)	7.6 x 7.6 x 15.6 (193 x 193 x 396)	8 x 8 x 16 (203 x 203 x 406)
Dry Weight, lb (kg)	38.09 (17.31)	25.95 (11.79)	2.07 (0.940)
Gross Area, sq in. (mm ²)	118.2 (76 262)	119.1 (76 843)	128.0 (82 585)
Net Area, sq in. (mm ²)	66.4 (42 841)	62.5 (40 325)	61.6 (39 744)
Compressive Strength, psi (kN/m ²)			
Gross Area	2878 (19 843)	1592 (10 976)	41 (283)
Net Area	5128 (35 356)	3115 (21 477)	85 (586)
lin ft (lb/ft) (kg/m)	255,135 (379 141)	142,205 (211 601)	3936 (5857)
	Mortar Joints	Mortar Joints	StyroBond Joints
Diagonal Tension Strength, psi (N/m ²)			
Gross Area	93.1 (642)	77.3 (533)	2.5 (17.2)
Net Area	164.8 (1136)	145.0 (1000)	5.1 (35.2)
Absorption, lb/cu ft (kg/m ³)	7.0 (112)	10.9 (175)	Negligible

Table 2
Total Load (Dead[†] + Live^{*}) on Load-Carrying Periphery Walls
of Typical AFCS and Wood Frame Construction Barracks Buildings

Building Size, ft (m)	Roofing System Type	Dead Load, lb/ft (kg/m)	Live Load, lb/ft (kg/m)	Total Load, lb/ft (kg/m)
20 x 20 (6.0 x 6.0)	Wood Deck and Felt	61.01 (91)	421.6 (627)	482.61 (718)
30 x 40 (9.1 x 12.2)	Wood Deck and Felt	85.93 (127)	632.5 (941)	718.43 (1069)
40 x 50 (12.2 x 15.2)	Wood Deck and Felt	111.52 (166)	843.3 (1255)	954.82 (1421)
20 x 20 (6.0 x 6.0)	Corrugated Steel	36.84 (55)	421.6 (627)	458.44 (682)
30 x 40 (9.1 x 12.2)	Corrugated Steel	47.91 (71)	632.5 (941)	680.41 (1012)
40 x 50 (12.2 x 15.2)	Corrugated Steel	61.52 (92)	843.3 (1255)	904.82 (1346)

CONCLUSION: The maximum load on this type of construction is 955 lb/ft (1421 kg/m) of wall. For 8 x 8 x 16 in. (203 x 203 x 406 mm) wall building blocks, this load converts to 1273 (578 kg) per unit, or a gross area stress of 10 psi (68.9 kN/m²).

[†]Weight of roofing system

^{*}40 lb/sq ft (195.2 kg/m) snow load

APPENDIX: COMPRESSION AND DIAGONAL TENSION TEST RESULTS

The tables and figures in this appendix present the results of compression and diagonal tension tests performed on block and wall sections of polyurethane foam blocks. Figure A1 shows the foam block specifications.

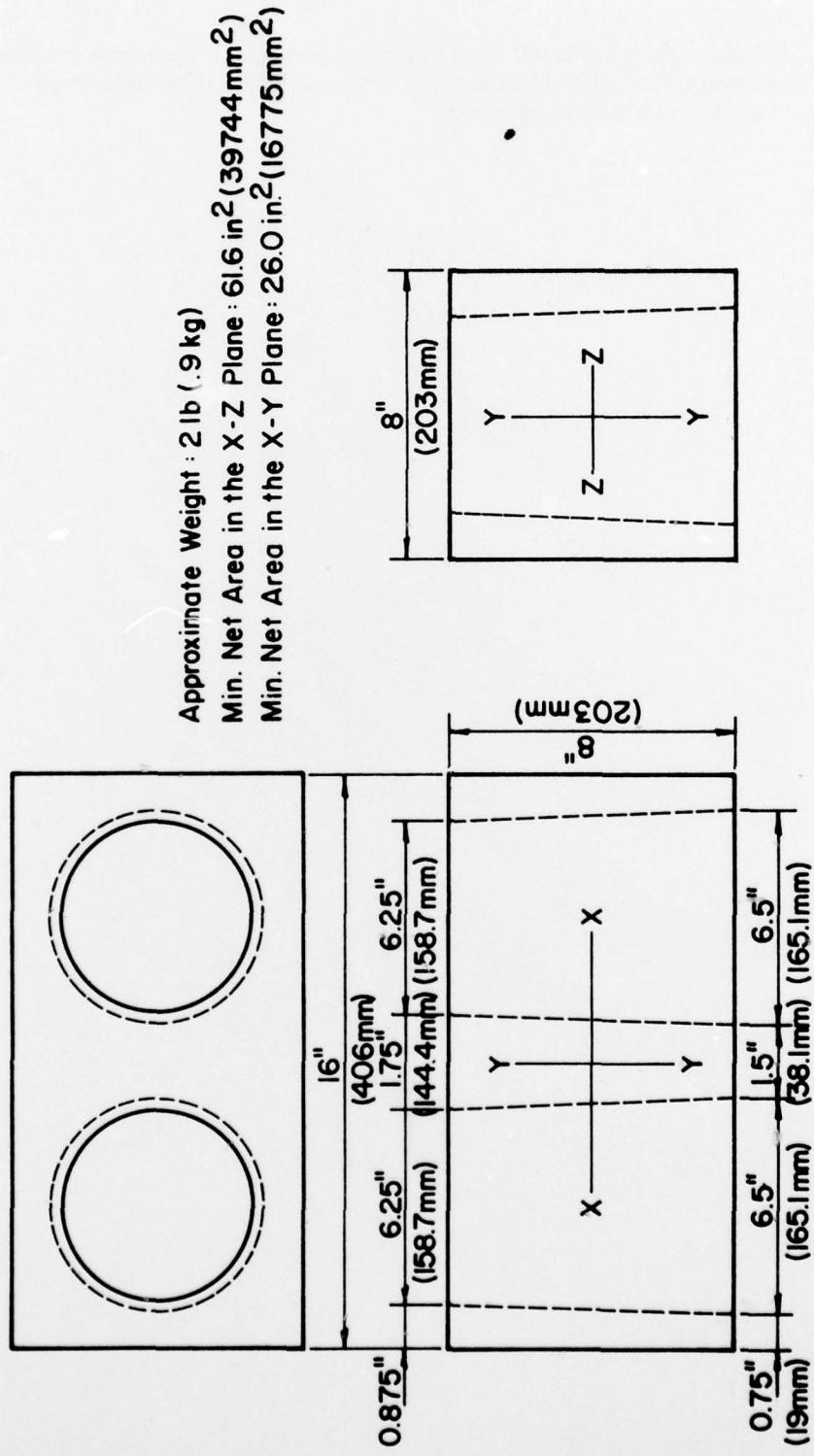


Figure A1. Foam block specifications.

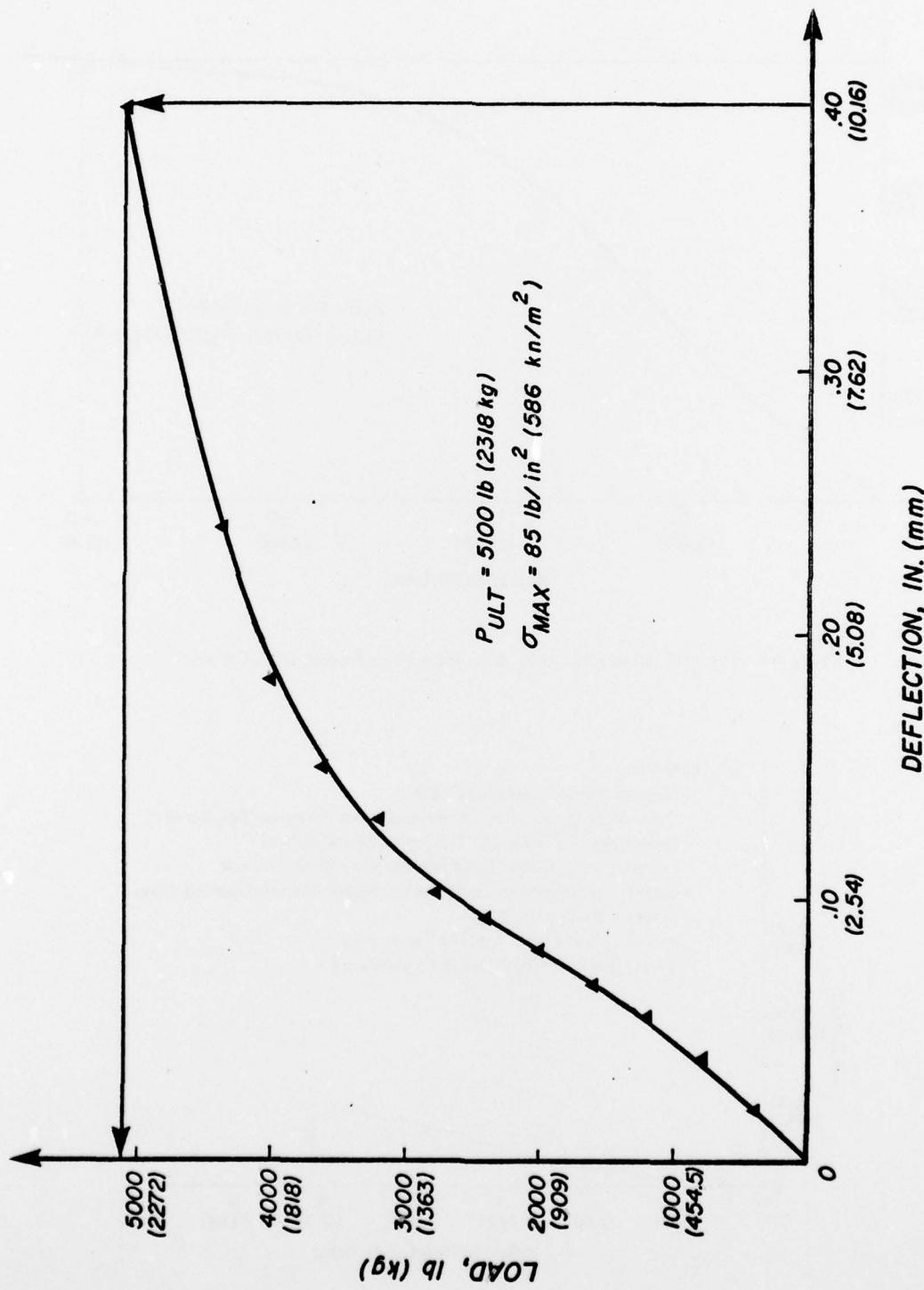


Figure A2. Typical load deformation curve for a foam block loaded normal to x axis.

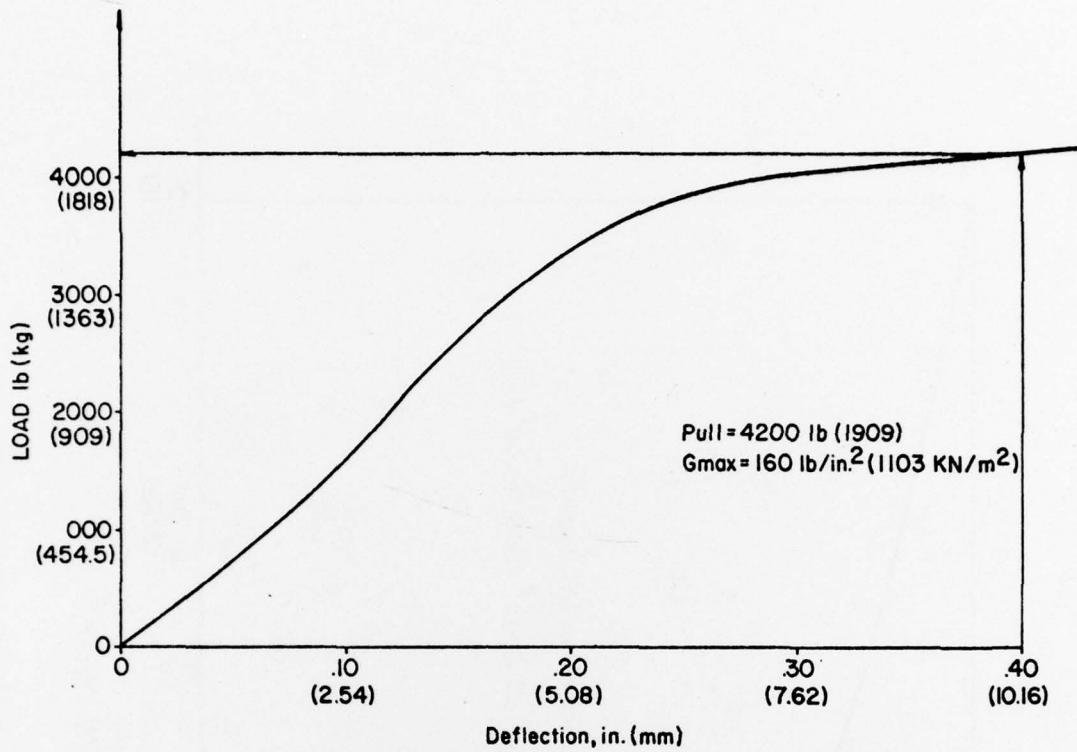


Figure A3. Typical load deformation curve for a block loaded from the side.

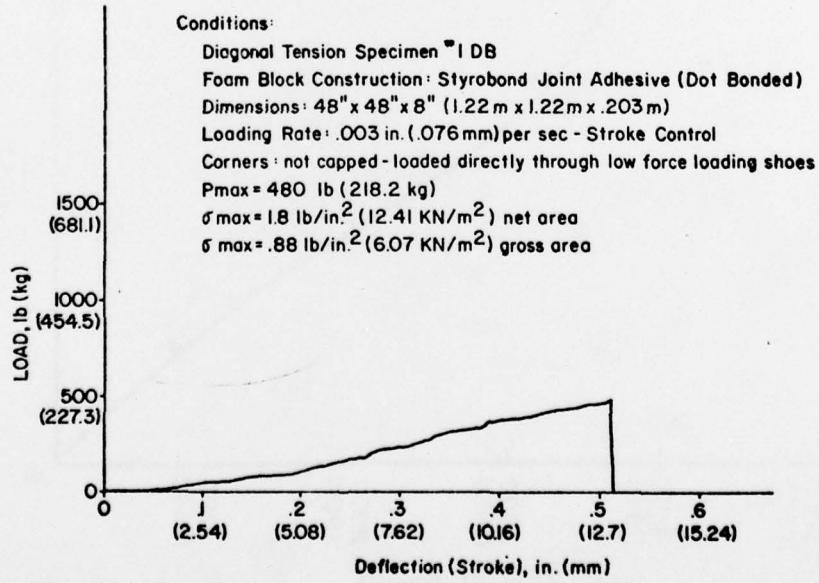


Figure A4. Diagonal tension test of dot bonded wall section (diagonal tension specimen #1 DB).

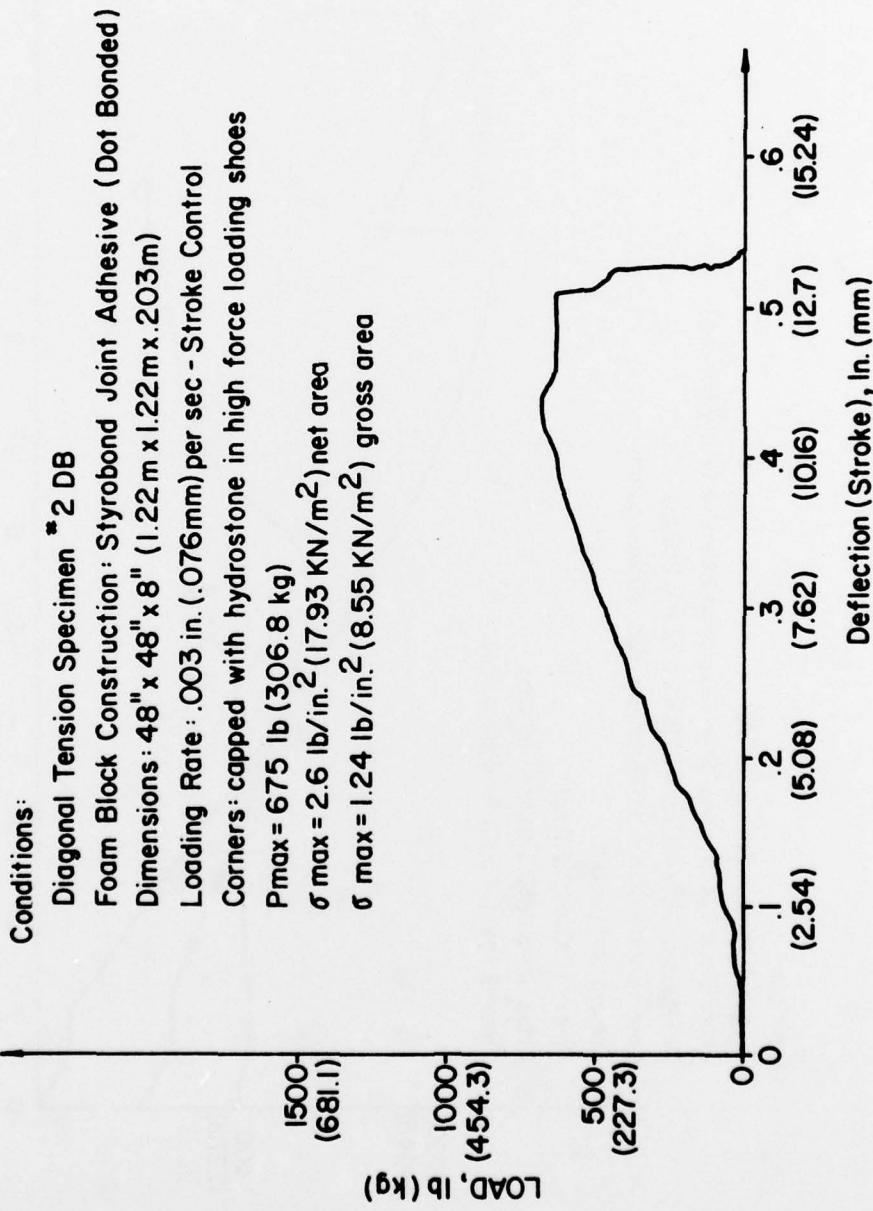


Figure A5. Diagonal tension test of dot bonded wall section (diagonal tension specimen #2 DB).

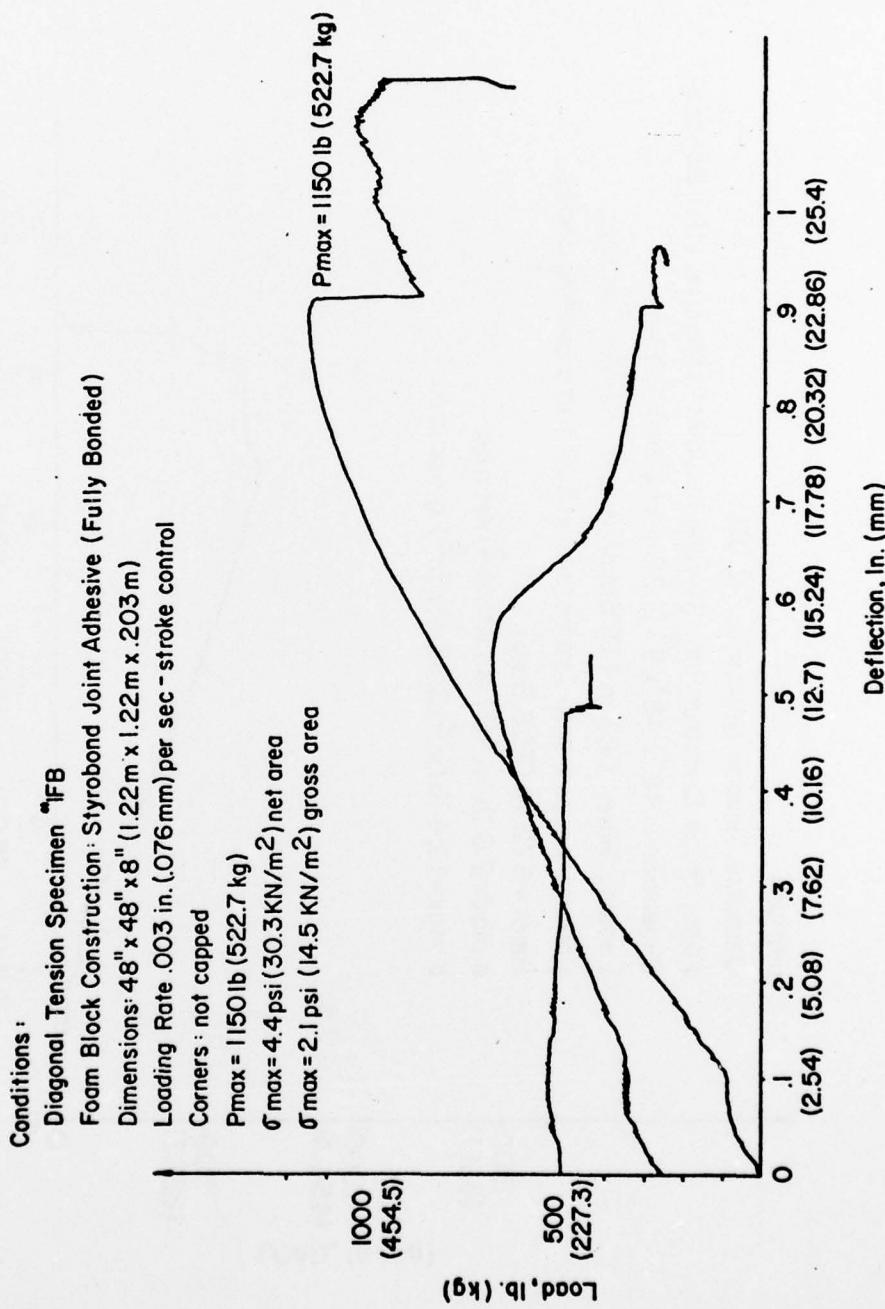


Figure A6. Diagonal tension test of full bonded wall section (diagonal tension specimen #1 FB).

Conditions:

Diagonal Tension Specimen #2 FB

Foam Block Construction: Styrobond Joint Adhesive (Fully Bonded)

Dimensions: 48" x 48" x 8" (1.22 m x 1.22 m x .203 mm)

Loading Rate: .003 in. (.016 mm) per sec

Corners: not capped

P_{max} = 1525 lb (693.2 kg)

$\sigma_{max} = 5.8 \text{ psi (39.99 KN/m}^2\text{) net area}$

$\sigma_{max} = 2.8 \text{ psi (19.31 KN/m}^2\text{) gross area}$

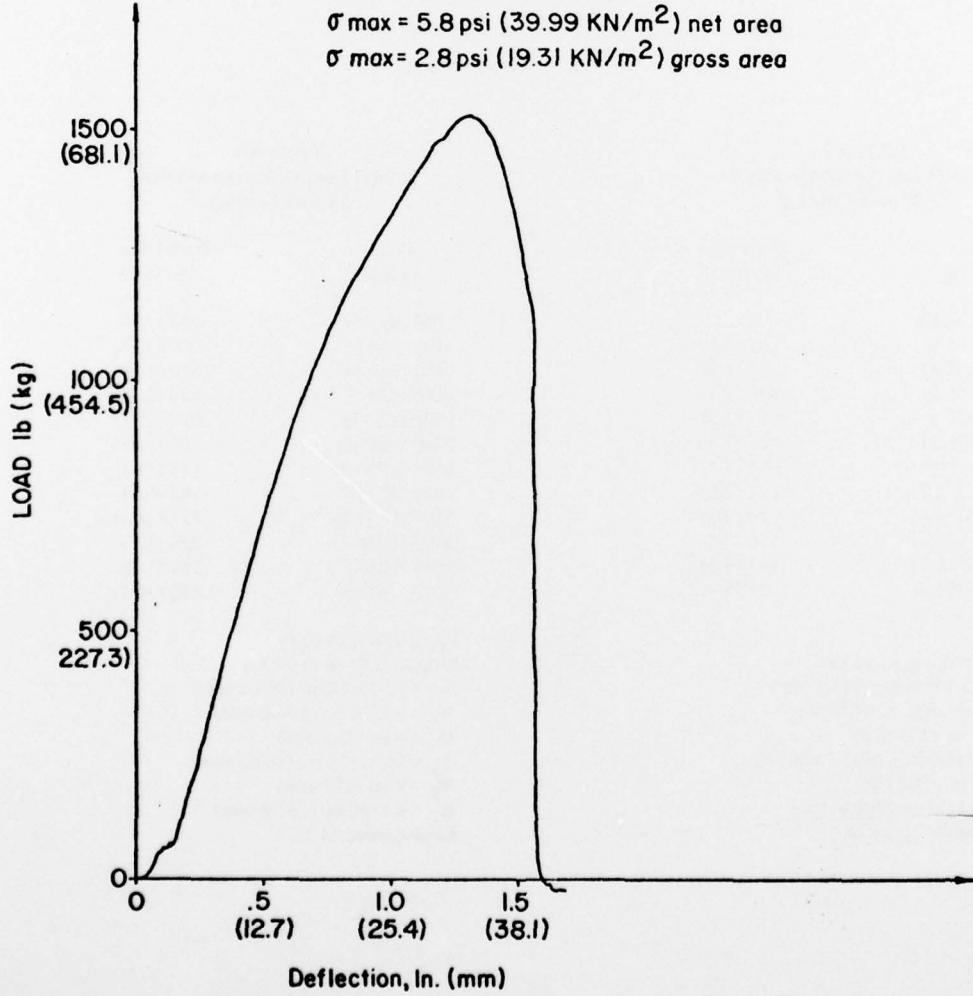


Figure A7. Diagonal tension test of full bonded wall section (diagonal tension specimen #2 FB).

Table A1
Results of Compression Tests on Foam Blocks

P _{ult} *	P _{ult} *
Normal Loading, lb (kg)	Side Loading, lb (kg)
5100 (2318)	3700 (1682)
6900 (3136)	4200 (1902)
5100 (2318)	4600 (2091)
4800 (2182)	
4400 (2000)	
average	

σ_{max} for normal loading = 85 lb/in² (586 kN/m²) net area

σ_{max} for side loading = 160 lb/in² (1103 kN/m²) net area

*Maximum load at 5 percent deformation in the direction of the applied load.

Table A2
Typical Load-Deformation Data
for Normal Loading

Load lb (kg)	Deflection in. (mm)
100 (45.45)	0
400 (181.8)	.02 (.5)
800 (363.6)	.04 (1.0)
1200 (545.5)	.055 (1.4)
1600 (727.3)	.067 (1.7)
2000 (909.1)	.081 (2.1)
2400 (1090.9)	.094 (2.4)
2800 (1272.7)	.101 (2.6)
3200 (1454.4)	.130 (3.3)
3600 (1636.4)	.150 (3.8)
4000 (1818.2)	.183 (4.6)
4388 (1994.5)	.24 (6.1)
(yield - 5 1/8)	

Weight = 2.0 lb (0.92 kg)

L_x = 15 14/16 in. (403.2 mm)

W_x = 8 1/16 in. (204.8 mm)

H_x = 8 in. (203 mm)

L_y = 8 14/16 in. (403.2 mm)

W_y = 8 in. (203 mm)

H_y = 8 1/16 in. (204.8 mm)

Load parallel to y-axis

Table A3
Typical Load-Deformation Data
for Side Loading

Load lb (kg)	Deflection in. (mm)
100 (45.45)	.000 (.0)
400 (181.8)	.030 (.075)
800 (363.6)	.058 (1.5)
1200 (545.5)	.080 (2.00)
1600 (727.3)	.099 (2.5)
2000 (909.1)	.117 (3.0)
2400 (1090.9)	.138 (3.5)
2800 (1272.7)	.164 (4.2)
3200 (1454.5)	.1915 (4.9)
3600 (1636.4)	.226 (5.7)
4000 (1812.2)	.284 (7.2)
4250 (1931.8)	.430 (10.9)

P_{max} 4280 (1945.4)

Weight: 2.07 lb (0.94 kg)

L_x = 15 15/16 in. (403.2 mm)

W_x = 8 1/16 in. (204.8 mm)

H_x = 8 in. (203 mm)

L_y = 15 15/16 in. (403.2 mm)

W_y = 8 in. (203 mm)

H_y = 8 1/16 in. (204.8 mm)

Load applied 11 to x

Table A4
Standard and Lightweight Concrete Block Compared to Foam Block

Specifications	Standard Concrete Block	Lightweight Concrete Block	Polyurethane Foam Block
Nominal Size, in. (mm)	8 x 8 x 16 (203 x 203 x 406)	8 x 8 x 16 (203 x 203 x 406)	8 x 8 x 16 (203 x 203 x 406)
Actual Size, in. (mm)	7.6 x 7.6 x 15.6 (193 x 193 x 396)	7.6 x 7.6 x 15.6 (193 x 193 x 396)	8 x 8 x 16 (203 x 203 x 406)
Dry Weight, lb (kg)	38.09 (17.31)	25.95 (11.79)	2.07 (0.940)
Gross Area, sq in. (mm ²)	118.2 (76 262)	119.1 (76 843)	128.0 (82 585)
Net Area, sq in. (mm ²)	66.4 (42 841)	62.5 (40 325)	61.6 (39 744)
Compressive Strength, psi (kN/m ²)			
Gross Area	2878 (19 843)	1592 (10 976)	41 (283)
Net Area	5128 (35 356)	3115 (21 477)	85 (586)
lin ft (lb/ft) (kg/m)	255,135 (379 141)	142,205 (211 601)	3936 (5857)
	Mortar Joints	Mortar Joints	StyroBond Joints
Diagonal Tension Strength, psi (N/m ²)			
Gross Area	93.1 (642)	77.3 (533)	2.5 (17.2)
Net Area	164.8 (1136)	145.0 (1000)	5.1 (35.2)
Absorption, lb/cu ft (kg/m ³)	7.0 (112)	10.9 (175)	Negligible

Table A5
Diagonal Tension Test on Foam Block Panels

Specimen No.	P _{max} lb (kg)	σ_{max} psi (kN/m ²) Gross Area	σ_{max} psi (kN/m ²) Net Area
1DB	480 (218.2)	.88 (6.07)	1.8 (12.41)
2DB	675 (306.8)	1.24 (8.55)	2.6 (17.93)
1FB	1150 (522.7)	2.1 (14.48)	4.4 (30.34)
2FB	1525 (693.2)	2.8 (19.30)	5.8 (39.99)
σ_{net}	average for dot bonded:	2.2 psi (15.17 kN/m ²)	
	average for fully bonded:	5.1 psi (35.16 kN/m ²)	
σ_{gross}	average for dot bonded:	1.1 psi (7.58 kN/m ²)	
	average for fully bonded:	2.5 psi (17.24 kN/m ²)	